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**Institute for Astronomy**  
*Honolulu, Hawaii 96822*

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This report covers the period from 1 October 1997 through 30 September 1998, and was compiled in October 1998.

## 1. INTRODUCTION

The Institute for Astronomy (IfA) is the astronomical research organization of the University of Hawaii (UH). Its headquarters is located in Honolulu on the island of Oahu near the University of Hawaii at Manoa, the main UH campus. The IfA is responsible for administering and maintaining the infrastructure for Haleakala Observatories on the island of Maui and for Mauna Kea Observatories (MKO) on the island of Hawaii.

More information is available at the Institute's World Wide Web site: <http://www.ifa.hawaii.edu/>.

## 2. STAFF

The scientific staff during this report period consisted of Timothy M. C. Abbott, Joshua E. Barnes, Ann M. Boesgaard, Peter M. Bryant, Kenneth C. Chambers, Laird M. Close, Antoinette Songaila Cowie, Lennox L. Cowie, Christophe Dumas, Harald Ebeling, Isabella M. Gioia, J. Elon Graves, Donald N. B. Hall, James N. Heasley, J. Patrick Henry, George H. Herbig, Klaus-Werner Hodapp, Joseph L. Hora, Esther M. Hu, David C. Jewitt, Robert D. Joseph, Nick Kaiser, Lev Kofman, John Kormendy, Jeffrey R. Kuhn, Barry J. LaBonte, Gerard A. Luppino, Alexander N. McClymont, Robert A. McLaren (Interim Director), Karen J. Meech, Donald L. Mickey, Malcolm J. Northcott, Tobias C. Owen, Andrew J. Pickles, Narayan S. Raja, John T. Rayner, Pui Hin W. Rhoads, A. Kathleen Robertson, Claude Roddier, François J.H. Roddier, David B. Sanders, Theodore Simon, Alan Stockton, David J. Tholen, Alan T. Tokunaga, John L. Tonry, R. Brent Tully, William D. Vacca, Richard J. Wainscoat, and Gareth Wynn-Williams.

Postdoctoral fellows included Amy Barger (NICMOS Postdoctoral Fellow), Nicholas Biver (James Clerk Maxwell Fellow), Olivier Hainaut, Roland Meier (NICMOS Postdoctoral Fellow), Katherine Roth (Hubble Fellow), and Gillian Wilson (Parrent Fellow).

Visitors included Jochen Eisloffel, Olivier Guyon, Masatoshi Imanishi, Naoto Kobayashi, Andreas Kull, Satoshi Miyazaki, Guillaume Molodij, and Bradford Smith.

## 3. MAUNA KEA OBSERVATORIES

The telescopes in operation during the report period were the UH 2.2 m telescope and the UH 0.6 m telescope; the 3 m NASA Infrared Telescope Facility (IRTF), operated by the UH under a contract with NASA; the 3.6 m Canada-France-Hawaii Telescope (CFHT), operated by the Canada-France-Hawaii Telescope Corporation on behalf of the National Research Council of Canada, the Centre National de la Recherche Scientifique of France, and the University of Hawaii; the 3.8 m United Kingdom Infrared Telescope

(UKIRT), operated in Hawaii by the Joint Astronomy Centre (JAC) based in Hilo on behalf of the Particle Physics and Astronomy Research Council of the United Kingdom; the 15 m James Clerk Maxwell Telescope (JCMT), a submillimeter telescope operated by the JAC on behalf of the United Kingdom, Canada, and the Netherlands; the 10.4 m Caltech Submillimeter Observatory (CSO), operated by the California Institute of Technology for the National Science Foundation; the Hawaii antenna of the Very Long Baseline Array (VLBA), operated by the National Radio Astronomy Observatory (NRAO); and the 10 m Keck I and Keck II telescopes of the W.M. Keck Observatory, which is operated by the California Association for Research in Astronomy for the use of astronomers from the California Institute of Technology, the University of California system, and UH.

Construction continued on the 8 m Subaru and Gemini Telescopes and on the Submillimeter Array (SMA).

This report covers in detail only the UH telescopes.

### 3.1 2.2 Meter and 0.6 Meter Telescopes

The report period was characterized by steady, productive observing and stable operation. No new instruments were commissioned on the 2.2 m telescope. This allowed us to reduce the number of engineering nights to 15, making more nights available for scientific research.

During the report period, imaging with CCDs remained the most common use of the telescope (40% of the observing time) and the bulk of the dark-moon observing time. A little over half of this was wide-field imaging using the Tektronix 2048 × 2048 CCD at the f/10 focus. Use of the new 8192 × 8192 mosaic CCD camera decreased to 15 nights scheduled in two separate runs. The 8192 × 8192 camera has a field of view of 19' × 19'. A field-flattener is installed as the dewar window when it is used at the f/10 focus of the 2.2 m telescope. High-resolution CCD imaging at the f/31 focus accounted for about one sixth of the CCD imaging, and the remainder of the CCD imaging used the UV-sensitive Orbit CCD, which has high quantum efficiency in the blue down to the atmospheric cutoff.

The use of the 2.2 m telescope for medium-resolution spectroscopy increased markedly in the report period to 22% of the observing time, most of which was scheduled during dark and gray periods. Two spectrographs are available on the 2.2 m telescope, the Wide Field Grism Spectrograph (used at the f/10 focus) and the High Angular Resolution Imaging Spectrograph (used at the f/31 focus with the tip-tilt secondary mirror).

Imaging with the 1024 × 1024 infrared camera (QUIRC) increased to 30% of the observing time. About three-quarters of these observations were performed at the f/10 focus, where the camera has a large field of view (3.2 × 3.2). The large format of this infrared camera has made it an extremely powerful tool for infrared imaging. It is in particularly high

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<b>Abstract</b> The Institute for Astronomy ~IfA! is the astronomical re-search organization of the University of Hawaii ~UH!. Its headquarters is located in Honolulu on the island of Oahu near the University of Hawaii at Manoa, the main UH cam-pus. The IfA is responsible for administering and maintain-ing the infrastructure for Haleakala Observatories on the is-land of Maui and for Mauna Kea Observatories ~MKO! on the island of Hawaii. More information is available at the Institutes World Wide Web site: <a href="http://www.ifa.hawaii.edu/">http://www.ifa.hawaii.edu/</a> .		
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demand for deep, wide-area infrared imaging surveys of distant galaxies. This camera was also used at the f/31 focus, where near diffraction-limited imaging over a  $60'' \times 60''$  field of view is possible in good conditions with a suitable guide star for the tip-tilt system.

The near-infrared spectrometer KSPEC was used for 8% of the observing time. Use of visitor instruments was very low, amounting to only 2 nights.

Scheduling of the telescope focused on minimizing instrument changes. During the report period, the average length of time an instrument was installed on the telescope was 7.6 nights. Problems with instruments most commonly occur after a change, so by minimizing the number of changes, observing efficiency was improved.

QUIST—a 25-cm telescope mounted on top of the 1024  $\times$  1024 camera and attached on the counterweight side of the 0.6 m telescope—was in heavy demand, and used for 64 nights. This telescope provides a field of view of  $29' \times 29'$  with pixels of  $1''.7$ , and is normally used remotely from Manoa. Observers normally execute their observations by means of a script, and the telescope performs them robotically; the observer checks progress periodically. QUIST was oversubscribed during the early part of the report period. Its usage was limited primarily by availability of the 1024  $\times$  1024 camera. QUIST was used on the 0.6 m telescope mostly during dark time. During the bright time, the 1024  $\times$  1024 camera was used on the 2.2 m telescope or CFHT.

Further progress was made in making documentation for the telescopes available via the World Wide Web. The URL for information relating to the 2.2 m and 0.6 m telescopes is <http://www.ifa.hawaii.edu/88inch>. The user manual, instrument manuals, and a telescope newsletter are available at this URL.

Scheduling periods for the telescopes are 6 month semesters: February–July (deadline September 15) and August–January (deadline March 15). The same scheduling periods are used for all the Mauna Kea telescopes.

### 3.2 Infrastructure

MKO has had commercial electrical power for ten years now. During the past year, two rooms at the summit that previously housed the controls for the old diesel generators were extensively renovated to accommodate terminal equipment for the fiber-optic communications system.

One of the rooms is used by GTE Hawaiian Tel to provide a wide range of high-bandwidth data circuits, as well as standard voice lines, between the summit observatories and the base facilities in Hilo and Waimea. The data links include an OC-12 ( $622 \text{ Mbit s}^{-1}$ ) for Subaru, DS-3's ( $45 \text{ Mbit s}^{-1}$ ) for CFHT, Keck, and Gemini, and a DS-1 ( $1.5 \text{ Mbit s}^{-1}$ ) for the JAC. The potential for expansion is essentially unlimited, being dependent only on the capacity of the terminal equipment. At the end of August, the voice and DS-1 services that had previously been carried by a microwave radio system were switched to the fiber, and the radio was decommissioned after many years of service.

The other renovated room is used as a hub for the MKO local area network, which interconnects all of the observatories and the Mid-Level Facilities at Hale Pohaku. This net-

work currently uses fiber distributed data interface (FDDI) technology. In the coming year, a staged transition to asynchronous transfer mode (ATM) will begin.

## 4. HALEAKALA OBSERVATORIES

The administrative staff consists of M. Maberry, D. O'Gara, K. Rhoden, K. Kimura, K. Ventura, and J. Perreira, and the technical staff included A. Distasio, E. Olson, M. Waterson, R. Zane, G. Nitta, J. Frey, C. Foreman, L. Hieda, K. Rehder, B. Lindsey, S. Rach, and B. Thompson.

### 4.1 Mees Solar Observatory

Mees Solar Observatory (MSO) supports IfA solar scientists in data acquisition by running diverse observational programs with its seven telescopes. The observatory regularly co-observes with the satellites *Yohkoh*, *Solar and Heliospheric Observatory (SOHO)*, and *Transition Range and Coronal Explorer (TRACE)*, and also participates in support of special satellite and ground-based observatory campaigns. One of the unique observational capabilities at Mees is the ability to perform measurements of the temporal evolution of photospheric vector magnetic fields. The observatory's complement of instruments includes the Imaging Vector Magnetograph, Haleakala Stokes Polarimeter, Mees CCD Imaging Spectrograph, Mees White Light Telescope, K-Line Imager, Coronal Limb Imagers, and a second K-line Imager.

See Sec. 9, Solar Physics, for information about the research projects at MSO.

### 4.2 LURE Observatory

LURE is a satellite laser ranging (SLR) observatory. LURE utilizes a high-powered pulsed laser to obtain distance measurements to satellites in Earth orbit. LURE is funded by the Space Geodesy and Altimetry Projects Office (SGAPO) of NASA Goddard Space Flight Center. The missions of the target satellites include monitoring of Earth resources and climate parameters, measurements of ocean levels and temperatures, plate tectonics, and improvement of the Global Positioning System (GPS), as well as special missions on the physics of tethered satellite systems. LURE provides range data to NASA 7 days a week, and improvements to the computer system and to the operational procedures will soon allow LURE to operate on a 24 hr schedule. LURE continues to be a top data producer in the worldwide network of cooperating SLR observatories.

### 4.3 AEOS-Haleakala Atmospheric Characterization Project

Haleakala Observatories is under contract during 1998–99 to the Air Force Research Laboratories to conduct a research program known as the AEOS-Haleakala Atmospheric Characterization (AHAC). This program supports the U.S. Air Force Advanced Electro-Optical System (AEOS) Telescope on Haleakala by providing comprehensive atmospheric characterization and timely prediction of inclement weather conditions at the observatory site. Data on optical distortion (seeing) and meteorological conditions will be

available on-line in near-real time, and will be archived for further analysis. The instrument suite that supports these site measurements includes a micrometeorological measurement system (MMS), a daytime/nighttime optical seeing monitor, a sound-powered radar system, and a network of remote meteorological systems linked by radio modems. The optical seeing monitor system will be improved to allow capture of image data at high frame rates, allowing computation of seeing statistics over intervals of  $<1$  s.

## 5. INSTRUMENTATION

### 5.1 Adaptive Optics

The new 36-actuator adaptive optics (AO) system built by the AO team has been nicknamed “Hokupaa” (immovable star, i.e., Polaris in Hawaiian). It was first tested on the sky in November 1997 and performed as expected. Data taken with the new system as well as with the old 13-actuator system were reduced and produced several new publications.

The first light of Hokupaa occurred on 7 November 1997. The instrument was mounted at the  $f/35$  focus of the CFHT. It took less than half a night to do the engineering tests, after which the instrument was operational for astronomical observations. The performance achieved was described at the SPIE conference No. 3353 on Adaptive Optical System Technologies held in Kona on 23–26 March 1998. Information on the system is also available on the Web at <http://www.ifa.hawaii.edu/ao>. Gains in Strehl ratio were observed up to a factor of 30, and stellar images with a full width at half-maximum of  $0''.068$  were obtained in the  $I$  band ( $0.936 \mu\text{m}$ ). This performance was observed on a mag 9.5 star. Similar performance was achieved on stars up to mag 12, beyond which it gracefully degraded with still noticeable image improvement beyond mag 16. The new instrument was used for astronomical observations from 7 to 17 November 1997 and was scheduled again at the CFHT from 1 to 6 July 1998. In both cases, it was used not only by the AO group, but also by a number of other IfA observers whose work is described elsewhere in this report. As previously, the AO team focused its efforts on two main programs: a study of the environment of young stars, and observations of solar system objects. These results are summarized in the stellar astronomy and solar system sections, respectively.

### 5.2 The Gemini Near-Infrared Imager (NIRI)

The 8 m Gemini North Telescope, now nearing completion on Mauna Kea, is designed to achieve unprecedented image quality and is unique in its optimization for low telescope emissivity. It is expected that these design features, together with the quality of the observing site, will make the Gemini North Telescope the best ground-based telescope for observations in the thermal infrared.

NIRI will be the main infrared imaging instrument on Gemini North. Its first task will be the commissioning of the telescope and a characterization of its performance.

NIRI will provide three pixel scales for scientific observations. The finest ( $0.02 \text{ arcsec pixel}^{-1}$ ) has been chosen to sample properly the expected image quality delivered by the adaptive optics system; the middle one ( $0.05 \text{ arcsec pixel}^{-1}$ )

is best matched to the image quality expected from tip-tilt corrected images on the best nights; and the widest field ( $0.12 \text{ arcsec pixel}^{-1}$ ) fills almost the whole unvignetted science field of the telescope. Produced by the Hughes Aircraft Santa Barbara Research Center (SBRC) under contract from Gemini, the science detector array will be a  $1024 \times 1024$  Aladdin array with  $27 \mu\text{m}$  pixels. Besides basic imaging, NIRI will provide the capability for grism spectroscopy at low to moderate spectral resolutions (600 and 2000 for  $J$ ,  $H$ , and  $K$ , and 1500 for  $L$ ), the capability to obtain coronagraphic imaging data, and the capability for polarimetric observations using a Wollaston prism with  $1''$  beam separation.

NIRI will be equipped with an internal on-instrument wave-front sensor (OIWFS) to keep differential flexure between the science channel and the OIWFS within acceptable limits. Optical wave-front sensors perform well almost everywhere in the sky, but an important class of scientific projects, studies of deeply embedded very young stars in nearby molecular clouds, is not able to utilize such a system. For this reason, and in light of recent advances in the noise performance of near-infrared detector arrays, the NIRI OIWFS will be a HAWAII (HgCdTe Astronomical Wide Area Infrared Imager)  $1024 \times 1024$  HgCdTe array.

During the report period, the design of NIRI was finalized and most of the fabrication work was done. NIRI is on schedule for shipment to the Gemini Hilo Base Facility in January 1999 and first use at the telescope in March 1999.

### 5.3 Infrared Camera and Spectrograph (IRCS) for the Subaru Telescope

Tokunaga (PI), Project Scientist N. Kobayashi, and co-investigators Hodapp, Rayner, Hora (IfA), Y. Kobayashi and T. Maihara (National Astronomical Observatory of Japan [NAOJ]), and T. Nagata (Nagoya) continued their work on the construction of the IRCS, a facility instrument for the 8.2 m Subaru Telescope at Mauna Kea. It will be a high-resolution spectrograph for  $1\text{--}5 \mu\text{m}$  ( $R = 20,000$ ), and a powerful slit-viewing camera. The camera section will have grisms for low to moderate spectral resolution (up to  $R = 2,000$ ). The instrument will use  $1024 \times 1024$  InSb arrays (the Aladdin arrays), one each for the camera and spectrograph sections. Major components have been purchased or constructed, and testing of hardware is underway. The instrument will be shipped to Hilo in February 1999, and the first test observations on the telescope are expected to be made about 5 months later.

### 5.4 Optical Detector Development

Tonry has pioneered the development a new type of CCD, the Orthogonal Transfer CCD (OTCCD), that is capable of transferring charge in two directions. With such a detector one can accomplish tip-tilt image-motion compensation “on-chip” rather than with movable optics as is usually done. Prototype devices have been developed by Tonry with Massachusetts Institute of Technology Lincoln Laboratory (MITLL). In fall 1998, the first large devices ( $2K \times 4K$ ) should be delivered to the IfA through the UH-MITLL Consortium, and two devices will be employed on the UH 2.2 m

telescope at the bent-Cassegrain focus as a “hitch-hiker camera,” available at all times for synoptic or other time-critical observations. It is expected that these devices will also be used at the European Southern Observatory (ESO) New Technology Telescope (NTT) and Mt. Stromlo, both sites where high-speed image motion compensation pays big dividends.

### 5.5 SpeX

SpeX is a medium-resolution 0.8–5.5  $\mu\text{m}$  cryogenic spectrograph being built at the IfA for the NASA IRTF. SpeX was funded by the National Science Foundation (NSF) in July 1994. The primary scientific purpose of the instrument is to provide maximum simultaneous wavelength coverage at a spectral resolving power that is well matched to many planetary, stellar, and Galactic features, and that adequately separates sky emission lines and disperses sky continuum. This requirement has resulted in an instrument design that uses prism cross-dispersers to provide spectral resolving powers of  $R \sim 1000$ –2000 simultaneously across 0.8–2.5  $\mu\text{m}$ , 2.0–4.2  $\mu\text{m}$ , or 2.4–5.5  $\mu\text{m}$ . SpeX will use an Aladdin 1024 $\times$ 1024 InSb array in its spectrograph and an Aladdin 512 $\times$ 512 InSb array in its infrared slit-viewer. SpeX is being designed and built by IRTF/UH staff: Rayner (PI), A. Denault (software engineer), P. Onaka (electrical engineer), W. Stahlberger (mechanical engineer), D. Toomey (project engineer), and D. Watanabe (instrument technician).

In July 1998, Rayner received NSF funding to add a high-speed infrared spectroscopy mode to SpeX. The new mode consists of a single dispersing prism and higher-speed read-out electronics, which will permit spectral observations of occultations and optimized observations of solid-state features in small solar system bodies across the range  $\sim 0.6$ –2.5  $\mu\text{m}$  at resolving powers of  $R \sim 150$ .

Much progress was made on instrument fabrication and testing during the year. During February 1998 infrared images were successfully obtained with an Aladdin II 1024 $\times$ 1024 array (courtesy of IRCS/Subaru) in the SpeX test dewar using the prototype array controller. Following testing of the prototype and design modifications to increase the full array readout speed to 10 Hz, fabrication of the two SpeX controllers (one for each array) was started in July. Also in July, major components of the cryostat cold structure were assembled and mounted inside the large vacuum jacket. Flexure testing of the cryostat confirmed finite element analysis predictions. The cryostat was successfully cooled down for the first time in September, achieving cooldown times and heat loads slightly better than predicted. SpeX will get first choice of an array from the NASA Planetary Astronomy Array Infrastructure Project (PAIDAI). Of the four arrays tested so far, one is considered to be of science grade. This array is cosmetically good and has a read-noise of 40 electrons rms and a median dark current of 0.2 electrons  $\text{s}^{-1}$  at 35 K. PAIDAI is producing a total of sixteen 1024 $\times$ 1024 InSb arrays and ten 512 $\times$ 512 InSb arrays.

Optical alignment and assembly is scheduled to begin toward the end of 1998, and the first all-up tests of the instrument are expected in May 1999, leading to first light at IRTF in about October 1999. Information and quarterly progress

reports about SpeX are available on the World Wide Web at <http://irtf.ifa.hawaii.edu/Facility/spex/spex.html>.

### 5.6 AEOS Spectrograph

The U.S. Air Force Advanced Electro-Optical System (AEOS) is a 3.63 m aperture telescope now nearing completion on Haleakala. Under contract to the Air Force, the IfA is building a dual-arm visible and near-infrared spectrograph to be installed in one of the AEOS coudé rooms. Institute personnel responsible for this project are Mickey (PI), Stockton, Hodapp, and Luppino. During the report period, the overall design was completed, camera optics were designed and procurement was begun, and detector electronics designs were completed. Detailed design and fabrication is now proceeding.

The spectrograph will utilize large-format array detectors to provide resolving power of at least 50,000 together with wide spectral coverage over the 0.5–2.5  $\mu\text{m}$  wavelength range. The “optical” arm will utilize a 4K $\times$ 4K CCD mosaic. UH is coordinating a consortium of astronomical institutions for the development of the HAWAII-2 2048 $\times$ 2048 format HgCdTe infrared arrays at the Rockwell Science Center. The new devices build on the design experience with the HAWAII-1 1024 $\times$ 1024 detector arrays (see Sec. 4.2), but the new arrays will include significant improvements. Most notably, the number of output amplifiers will be user selectable between 4 and 32 amplifiers for the full array, allowing both relatively slow, low-cost implementation of the devices and more costly high-speed systems.

During the report period, the multiplexer design was finalized and checked, and fabrication of the multiplexers at Rockwell was begun. The first engineering-grade devices are expected early in 1999.

## 6. GALACTIC AND EXTRAGALACTIC STUDIES

Tonry, J. Blakeslee (Caltech), E. Ajhar (National Optical Astronomy Observatory [NOAO]), and A. Dressler (Carnegie Observatories) are completing a program of distance determination to nearby elliptical and S0 galaxies using the method of surface brightness fluctuations formulated by Tonry. While the surface brightness of a galaxy is invariant with distance, the rms fluctuation about this mean will depend on the number of unresolved stars sampled by each detector pixel, and will be inversely proportional to the distance of the galaxy. This method is being applied to make an estimate of the Hubble constant, infall towards the Virgo Cluster, and motions toward Centaurus and the “Great Attractor.” In collaboration with former UH student J. Jensen (Gemini), R. Thompson and M. Rieke (Univ. of Arizona), T. Lauer (NOAO), M. Postman (Space Telescope Science Institute [STScI]), and R. Weymann (Carnegie), Tonry is using observations of fluctuations by the *Hubble Space Telescope* (HST) Near-Infrared Camera and Multiobject Spectrometer (NICMOS) to probe large-scale flows to distances as great as 10,000  $\text{km s}^{-1}$ .

Tonry continues a campaign to exploit gravitational lenses to learn about cosmology. With M. Franx (Leiden) and C. Kochanek (Harvard), he has written several papers on

velocities and dispersions from Keck spectroscopy of gravitational lenses. Tonry has begun studies of gravitational lenses with his “hitch-hiker” camera (see Sec. 4.4) on the UH 2.2 m telescope to monitor variations in QSO brightness that can be used to determine a time delay, and hence, distance to the lens.

Tully has continued work on the extragalactic distance scale and studies of the peculiar velocity field of the Local Supercluster. Improvements in the luminosity–rotation rate method of distance determinations have resulted from (1) better determination of inclination corrections, (2) the acquisition of far larger and more complete calibration samples, and (3) many new zero-point calibrators from the *HST* Cepheid programs. Tully now finds  $H_0 = 77 \pm 4 \text{ km s}^{-1} \text{ Mpc}^{-1}$  (95% statistical certainty). Errors are now dominated by potential systematic effects.

Tully collaborates with E. Shaya (Hughes STX/Goddard), P. Peebles (Princeton), and S. Phelps (Princeton) on a Least Action reconstruction of the orbits of galaxies in the Local Supercluster, in order to understand the peculiar velocity field. The best models require mass assignments to most galaxies of  $M/L \sim 150 M_\odot/L_\odot$ , and the overall model has  $\Omega_0 \sim 0.25$ . However, knots of E/S0 galaxies are found to have much higher mass requirements, as high as  $M/L \sim 1000 M_\odot/L_\odot$ . In a volume-limited sample, the knots of E/S0 galaxies may supply only 10–15% of the light but may have 40–50% of the mass associated directly with galaxies.

Tully is also collaborating with W. Saunders (Royal Observatory, Edinburgh), B. Mobasher (Imperial College), and others on an observing program to acquire  $I$  and  $K'$  photometry and H I linewidths on a sample of 1300 galaxies selected with all-sky uniformity from an *IRAS* redshift survey. *IRAS* selection and  $K'$  photometry assures more even coverage of the sky than provided by previous studies.

Kormendy and R. Bender (Munich) completed a paper on spectroscopy of the double nucleus of M31 that used the CFHT with the Subarcsecond Imaging Spectrograph. They confirm the steep rotation and velocity dispersion gradients that imply that M31 contains a  $3 \times 10^7 M_\odot$  central dark object. At resolution  $\sigma_* = 0''.27$  (dispersion radius of the PSF), the maximum bulge-subtracted velocity dispersion of nucleus P2 is  $287 \pm 9 \text{ km s}^{-1}$ . However, the brighter nucleus, P1, is colder than the bulge, with  $\sigma \approx 100 \text{ km s}^{-1}$  at  $r \approx 1''$ . In fact, the nucleus is cold on both sides of the center. The results qualitatively confirm Tremaine’s 1995 model that both nuclei are a single eccentric disk of stars orbiting a central black hole (BH). The velocity center is displaced from P2 toward P1. The rotation curve is asymmetric; this is confirmation of the model’s essential idea that stellar orbits are elongated and coherently aligned. The model predicts that P1 and P2 should have the same stellar population. This is observed: P1 is more similar to P2 than it is to the bulge, or to a globular cluster, or to M32. This makes it unlikely that P1 consists of an accreted stellar system. The observation that there is cold light on both sides of the center implies, in the context of the model, that some stars have escaped from the P1–P2 alignment and have phase-mixed around the galaxy’s center.

The dispersion peak in M31 coincides with a cluster of

ultraviolet-bright stars seen in *HST* images. Kormendy and Bender propose that the BH is in this cluster. Its center is displaced by  $0''.06$  from the center of the bulge. If there is a  $3 \times 10^7 M_\odot$  BH in the UV cluster, then the center of mass (COM) of the bulge, nucleus, and dark object coincides to  $0''.017 \pm 0''.016$  with the center of the bulge. Therefore, the asymmetry of the stars in the double nucleus supports the suggestion that the BH is in the UV cluster. If the stars have a normal mass-to-light ratio, then the location of the COM also confirms the mass of the BH, largely independent of dynamical models.

Kormendy continued work on the black hole search as part of the “Nuker” team (D. Richstone, Michigan, PI) using *HST* to obtain photometry and kinematic measurements of the central parts of early-type galaxies. Gebhardt *et al.* (including Kormendy) completed a paper on the discovery of a central dark object in the elliptical galaxy NGC 3379.

Gioia, Henry, and graduate student C. Mullis are using the deepest region of the *ROSAT* All-Sky Survey, the so-called North Ecliptic Pole (NEP), to produce an X-ray-selected sample of distant clusters. A recent discovery is a cluster at  $z = 0.82$  with a filamentary optical structure. The cluster has a high velocity dispersion. X-ray maps obtained with the High Resolution Imager (HRI) onboard *ROSAT* show the presence of hot gas in the same regions of the optical filaments. This is reminiscent of the initial formation of proto-clusters described as matter flowing along filaments—a process that may be taking place in this distant cluster. The sample will allow the study of the evolutionary properties of X-ray clusters and also the characterization of the three-dimensional large-scale structure of the universe by studying the cluster-cluster correlation function.

Gioia, in collaboration with M. Donahue (STScI), Shaya, F. Hammer (Paris-Meudon), and O. Le Fèvre (Marseille), is analyzing *HST* images for lensing clusters and distant clusters from the *Einstein* Observatory Medium Survey X-ray sample. Spectroscopic measurements of the arcs’ redshifts and those of the cluster galaxies are being obtained to determine the cluster velocity dispersions. These measurements will be used to determine the lensing parameters to be applied to the *HST* data. Observations with the *Advanced Satellite for Cosmology and Astrophysics* (ASCA) and *ROSAT* HRI are also available. The X-ray data will provide the necessary ingredients (temperature and structure of the hot gas) to measure the cluster mass, to be compared with the mass determined from the lensing.

Gioia, in collaboration with colleagues at Milan and Bologna, is also focusing on the search for X-ray-selected BL Lac objects and active galactic nuclei (AGNs) in pointed images of *ROSAT*. The resulting samples will be useful in studying the statistical properties, luminosity functions, and cosmological evolution of BL Lac objects and AGNs, and they will place new observational constraints on the current theoretical models of emission.

Optical searches for clusters have been traditionally limited to Galactic latitudes  $|b| > 20^\circ$  because of the obscuration and stellar confusion at lower Galactic latitudes. However, hard X-rays can penetrate the Galactic plane even at Galactic latitudes approaching zero. The limiting factor is the

equivalent hydrogen column density that rises only slowly toward the plane, making the X-ray “zone of avoidance” much narrower than the optical one, which occupies nearly a third of the sky. A search for galaxy clusters behind the plane conducted by Ebeling, Mullis, Tully, and Pickles takes advantage of these facts by selecting cluster candidates by their spectral X-ray hardness in the *ROSAT All-Sky Survey Bright Source Catalogue*. While many of the sources thus selected turn out to be of Galactic origin (mainly X-ray bright stars and X-ray binaries), a fair fraction ( $\sim 20\%$ ) could be confirmed as clusters of galaxies in imaging and spectroscopic follow-up observations with the UH 2.2 m telescope. So far, more than 60 galaxy clusters have been detected in the X-ray data and spectroscopically confirmed in the optical; 80% of these are new discoveries.

When completed next year, this sample of clusters of galaxies behind the Galactic plane will, for the first time, allow studies of large-scale structure and streaming motions to extend over the whole sky, thus finally closing the Galactic gap that has been a limiting factor for so long.

Graduate student G. Canalizo is continuing her spectroscopic observations of host galaxies of QSOs lying between the bulk of the classical QSOs and the ultraluminous infrared galaxies in the far-infrared two-color plot. Models of the stellar populations that reproduce the observed spectra indicate that virtually all of these hosts include a significant contribution from a fairly recent post-starburst population. Canalizo is attempting to relate the average of the post-starburst component to other observable parameters in an effort to test the hypothesis that ultraluminous infrared galaxies are progenitors of at least some classical QSOs.

Stockton, Canalizo, and S. E. Ridgway (Johns Hopkins) have been examining fields of quasars at  $z \sim 1.5$  to search for galaxies that are already  $\sim 4$  Gyr old at this redshift. Over 200 fields have been examined via a photometric sieve procedure, and about a dozen promising candidates have been found. When confirmed spectroscopically, such objects can constrain both cosmological parameters and galaxy formation mechanisms.

Stockton, Canalizo, and Ridgway also began to explore emission-line objects in the 915 nm airglow window. Most cases of strong emission at this wavelength should be one of  $H\alpha$  at  $z \sim 0.39$ ,  $[O\text{ III}]$  at  $z \sim 0.84$ ,  $[O\text{ II}]$  at  $z \sim 1.46$ , or  $Ly\alpha$  at  $z \sim 6.52$ . Deep Keck imaging and spectroscopy with LRIS (Low Resolution Imaging Spectrometer) have been obtained of two fields so far. Many emission-line objects have been detected, including some  $Ly\alpha$  candidates, but none of the latter have certain confirmations yet.

Kaiser, graduate student H. Dahle, and M. Hudson and S. Gwyn (Univ. of Victoria) have studied galaxy-galaxy lensing in the Hubble Deep Field. A tangential distortion of background source galaxies around foreground lens galaxies in the Hubble Deep Field was detected at the 99.3% confidence level and was used to determine the Tully-Fisher relation at intermediate redshifts. A comparison with the local Tully-Fisher relation indicates that intermediate-redshift galaxies are fainter than local spirals by  $1.0 \pm 0.6$   $B$  mag at a fixed circular velocity. This is consistent with some spectroscopic studies of the rotation curves of intermediate-redshift galax-

ies, and suggests that the strong increase in the global luminosity density with redshift is dominated by evolution in the galaxy number density.

Graduate student D. Clowe, Kaiser, Luppino, Henry, and Gioia have measured the weak lensing effect for two  $z \approx 0.8$  clusters. They detect a shear signal from the distortion of distant background galaxies for each of two rich, X-ray-luminous clusters of galaxies, MS 1137+66 at  $z = 0.783$  and RXJ 1716+67 at  $z = 0.813$ . The shear signal is measured over the range  $100 < r < 700\ h^{-1}$ . Assuming the background galaxies lie in a sheet at  $z = 2$ , they find a mass of  $2.45 \times 10^{14}\ h^{-1}M_{\odot}$  and  $M/L_v = 270\ h$  at  $500\ h^{-1}$  kpc radius for MS 1137+66, and a mass of  $2.6 \times 10^{14}\ h^{-1}M_{\odot}$  and  $M/L_v = 190\ h$  for RXJ 1716+67 at the same radius. Both the optical light maps and weak lensing mass maps of RXJ 1716+67 show two spatially distinct subclusters, as well as a long filamentary structure extending out of the cluster to the northeast. In contrast, MS 1137+66 is an ultracompact massive cluster in both mass maps and optical light maps, and contains a strongly lensed arc system in the cluster core. These data add to the growing number of massive clusters at  $z \sim 0.8$ .

Kaiser, Wilson, Luppino, Kofman, Gioia, M. Metzger (Caltech), and Dahle presented a photometric and weak lensing analysis of the  $z = 0.42$  supercluster MS0302+17 using deep  $I$  and  $V$  band images taken with the UH8K CCD mosaic camera at the CFHT. They have measured the gravitational shear from a sample of  $\approx 30,000$  faint background galaxies in the range  $22 < m_I < 26$  and find this correlates strongly with that predicted from the early-type galaxies if they trace the mass with  $M/L_B \approx 250\ h$ . Cross-correlation of the measured mass surface density with that predicted from the early-type galaxy distribution shows a strong peak at zero lag, and at separations  $> 200\ h^{-1}$  kpc the early galaxies trace the mass very accurately. This result is quite surprising, as it is generally thought that early-type galaxies are strongly biased toward dense regions and that the mass, like the galaxies in general, is more broadly distributed. In this supercluster at least, the mass appears to be just as concentrated as in the early-type galaxies, and these data would argue for a very low cosmological density parameter.

## 7. STAR FORMATION AND INTERSTELLAR MATTER

Herbig continued work on diffuse interstellar bands (DIBs). In a large program, now completed, he established that (1) DIB strength depends upon the column density of  $H\text{ I}$ , not  $H_2$ , in diffuse clouds; (2) it does not depend on whether grains or gas in the line of sight have been shocked; (3) nor does it depend upon the shape of the interstellar reddening law; and (4) the DIB carriers appear to be concentrated near the surfaces of diffuse clouds, not in the cold dense interiors. Furthermore, (5) Herbig found no sign of DIBs in emission (as the result of fluorescence) on low-resolution spectra of reflection nebulae.

Ongoing work by Herbig, using spectra from High Resolution Echelle Spectrometer (HIRES) on the Keck I telescope, shows no evidence for the presence of the  $3240\ \text{\AA}$  band of free  $C_{60}$  in heavily reddened OB stars; this inves-



tigation has been greatly assisted by the availability of new laboratory spectra of  $O_3$ , whose atmospheric structure is dominant in this region. It is clear that the  $C_{60}$  molecule cannot account for any of the known DIBs. Herbig has obtained a new series of HIRES spectra that are being examined in a specific search for features of carbon-containing polyatomic molecules and their negative ions that have been found in the laboratory in the last few years, and that have been suggested as plausible interstellar species.

As reported last year, Herbig, in collaboration with D. McNally (University College London) observed the spectrum of the 8 mag B8 star HD 12895 in April 1997 as comet Hale-Bopp passed in front of it. This was to determine if the DIB spectrum might be detectable in absorption in the cometary coma, an idea that springs from the possibility that cometary nuclei, formed in the circumstellar disk of the early Sun, might contain the DIB carriers. The spectrograms obtained with HIRES on Keck I at  $R = 45,000$  have now been completely reduced and the results discussed. No convincing signs of DIBs in the coma of Hale-Bopp were found, in agreement with similar observations of comet P/Halley in 1986.

Herbig's extensive study of the young cluster IC 348, in the Perseus OB association, has now been published. It appears that star formation in the region now occupied by the association has been underway for 10–20 Myr, and IC 348 represents just a minor ongoing episode in the larger picture. Herbig is now pursuing a number of related issues that arose as a consequence of this investigation, in particular a search for low-mass counterparts of the massive association members, which ought to be dispersed over the large area now occupied by the OB stars. He has also begun a search, using the slitless grism arrangement at the  $f/10$  focus of the UH 2.2 m telescope, for  $H\alpha$  emitters in older OB clusters such as  $h$ ,  $\chi$  Per. The conventional view is that stars in the T Tauri mass range ought not to be detectable there, their disk/accretion activity having subsided.

The pre-main-sequence star EX Lupi, type object of the Exor eruptive variables, underwent a minor brightening to  $V = 11$  in June 1998. Alerted to this event by A.F. Jones of the New Zealand Variable Star Organization, Boesgaard and graduate student A. Stephens, who happened to be at the telescope at that time, obtained HIRES spectra. These spectra are now being analyzed by Herbig.

Tokunaga and S. Wada (Univ. of Electro-communications) continued their work on understanding the nature of quenched carbonaceous composite (QCC), a laboratory analog to the carbonaceous material in the interstellar medium. As an amorphous material containing aromatic hydrocarbons, QCC provides an alternative to the polycyclic aromatic hydrocarbon (PAH) hypothesis as an explanation for the infrared emission features observed at 3.29, 6.2, 7.7, 8.6, and 11.3  $\mu\text{m}$ . Laboratory experiments show that a hydrogen-deficient sample of QCC has an ultraviolet absorption at about 250 nm. The position and profile of this band is in close agreement with that observed around hydrogen-deficient post-AGB stars such as R Coronae Borealis. This type of QCC has a ribbonlike structure.

Tokunaga, graduate student M. Cushing, and N. Koba-

yashi (NAOJ) have obtained 1.4–2.5  $\mu\text{m}$  spectra of very faint low-mass objects in the  $\rho$  Oph dark cloud using the Near-Infrared Camera on the Keck I telescope. These objects have estimated masses as low as  $0.02 M_{\odot}$ . Their goal is to understand the nature of these faint sources and to confirm, if possible, the very low masses attributed to these sources. The sample shows that 50% of the sources have evidence of water absorption. The other sources appear to be featureless, highly reddened sources typical of Type I sources. Analysis of these spectra is in progress.

Using NSFCAM on IRTF, Rayner and collaborators T. Greene (NASA Ames) and J. Najita (STScI) have been conducting a low-resolution spectroscopic survey of a sample of young, high-mass stars to identify CO overtone emission sources and study the frequency and lifetimes of disks around high-mass stars. Several new sources have been found. These and previously known high-mass star disks have been observed at high spectral resolution with CSHELL on IRTF to investigate disk kinematics and gas excitation.

Rayner and collaborators A. Tieftrunk (Max-Planck-Institut, Bonn), S. Megeath (MIT Haystack Observatory), and T. Wilson (MPI Bonn) completed a study of the distribution of dense gas ( $NH_3$ ) and star-forming cores (2  $\mu\text{m}$ ) in the W3 giant molecular cloud complex. In related work, Simon, Rayner, and S. Megeath (now at Center for Astrophysics) conducted *HST* NICMOS imaging of the environs of W3 IRS5 in search of low-mass star formation.

Close continued investigating circumstellar disks around young stars with adaptive optics. This has led to the first measurement of the properties of dust in circumbinary disks. With a graduate student D. Potter, the first polarization map of a circumbinary disk was obtained. The observed polarization pattern of UY Aur proved that circumbinary dust exists in a plane of dust. With M. Simon and T. Beck (State Univ. of New York at Stony Brook), Close found that the binary frequency in the Orion Trapezium cluster is the same as that of the field, and that massive brown dwarfs were rare in the cluster.

## 8. STELLAR ASTRONOMY

Boesgaard continued her work on studies of the light elements in late-type stars.

UH graduate student A. Stephens, Boesgaard, J. King (STScI), and C. Deliyannis (Indiana) used the CFHT for an extensive search for beryllium (Be) in the atmospheres of lithium-deficient F and G dwarfs. New Li estimates for the entire sample were derived using previously published equivalent widths and updated, consistently calculated stellar parameters. The new abundances confirm the suspicion that F stars that deplete Li by factors of 10–200 may also be Be deficient. Photospheric Be concentrations range from near-meteoritic levels in G dwarfs to factors of 10–100 below this assumed initial abundance in hotter stars. Significant Be deficiencies appear in stars that populate a 600 K wide effective temperature window centered on 6500 K. This Be abundance gap is reminiscent in the Li gap observed in open clusters. Also, they identified 12 probable “110 Herculis” stars, objects that exhibit a depleted, but detected, surface concentration of both Li and Be. These Her stars provide a powerful

means of differentiating between the possible physical processes responsible for the light element abundance patterns. Of all the mechanisms proposed to explain the Li and Be underabundances in late-type stars, rotationally induced mixing, a turbulent blending of material beneath the surface convection zone due to the onset of instabilities from superficial angular momentum loss, predicts both the observed light element depletion morphology as well as the existence of 110 Her analogs. Of the models presented, these “Yale” mixing models provide the most plausible explanation of the observed Li and Be abundances.

Boesgaard, Deliyannis, Stephens, and D. Lambert (Univ. of Texas) used the Goddard High Resolution Spectrograph (GHRS) with the *HST* to observe the B I region at 2497 Å in nine F and G dwarfs of approximately solar metallicity. The stars were selected because they have a variety of Li and Be deficiencies. Most of the nine stars were newly observed at 3131 Å for Be II and 6708 Å for Li I at high spectral resolution and high signal-to-noise ratios at the Keck I telescope, the CFHT, and the UH 2.2 m telescope. Spectrum synthesis calculations, including non-LTE effects in B and Li, were used to determine the Li and Be abundances or upper limits, as well as B abundances in their nine program stars and in five other stars from the *HST* archive.

The stars in this sample originate from the region on the ZAMS of the Li (and Be) dip. In spite of large deficiencies in Li and Be, there is a striking uniformity in the B abundances, i.e., there is no B dip. For the coolest and most evolved star in the sample,  $\zeta$  Her A, the B abundance is a factor of 3 lower than the mean for the other stars. This star also has the largest Be deficiency (more than a factor of 60) and the largest Li deficiency (more than a factor of 500). These data, together with other studies of the Li dip, argue strongly against diffusion and mass loss and in favor of slow mixing as the cause of the Li and Be dip and the absence of a B dip.

Six stars with  $[\text{Fe}/\text{H}]$  from  $-0.75$  to  $+0.15$  have Be abundances ranging from the maximum of the sample to a factor of 4 (0.6 dex) below the maximum, yet these stars have a B/Be ratio that is constant to within  $\pm 0.10$  dex and that is close to the predictions of Galactic cosmic-ray spallation of 10–15. This indicates that the Galactic cosmic-ray production of B and Be is not uniform relative to the production of elements such as Fe by nucleosynthesis in stars.

Boesgaard, Deliyannis, Stephens, and King used Keck I and HIRES to make observations at  $R = 45,000$  ( $= 3$  pixels) of seven stars near the turnoff of the old, metal-poor globular cluster M92. In three of these stars, there are S/N ratios of 40 per pixel, and in the other four the S/N is near 20. They find that star 18 has a high Li abundance,  $\log N(\text{Li}) = 2.5$ , about a factor of 3 larger than that in stars 21 and 46. The Li abundance in star 18 is high compared to the halo field star plateau, and is similar to that in the remarkable Li-rich halo field star BD+23°3912. In addition, there is a dispersion in Li abundance in the seven stars studied that covers the range of a factor of 3.

They attempted to determine whether the high Li in star 18 is due to less-than-average Li depletion in this star from an even higher initial abundance, as predicted by the Yale rotational models, or is due to the extraordinary action of Li

production mechanisms in the material that formed this star. They found no convincing evidence that favors Li production: (1) Stars 18, 21, and 46 have identical Ba abundances, which argues against Li production carrying an s-process signature; (2) these three stars have indistinguishable Ca, Cr, Fe, and Ti, which argues against supernova Li production; (3) from the strengths of the Mg, Ca, and Fe lines there is no convincing observational evidence for  $\nu$ -process production of Li; and (4) the similarity in age of these cluster stars argues against cosmic-ray Li production that requires age differences of Gyrs. The most likely explanation for the Li dispersion is differential Li depletion from a (possibly significantly) higher primordial Li abundance due to differences in the initial angular momentum in each star followed by spin-down; the most rapid rotators destroy the most Li, whereas the initially slower rotators preserve more Li.

Using high-resolution, moderate signal-to-noise ratio spectroscopy obtained with the Keck I Telescope and HIRES, King, Stephens, Boesgaard, and Deliyannis have derived abundances of several elements in subgiants near the M92 turnoff. The  $[\text{Fe}/\text{H}]$  of  $-2.52$  for the M92 stars is a factor of 2 lower than the abundance derived from its red giant members. As a consistency check they also analyzed the metal-poor field star HD 140283 and find an Fe abundance in agreement with many previous determinations. They also note possible evidence for  $[\text{Fe}/\text{H}]$  differences within M92. Their spectroscopic analysis suggests that the M92 reddening,  $E(B-V)$ , may be 0.04–0.05 mag greater than canonical values, but various uncertainties mean that this conclusion is not definitive; the significant difference in interstellar Na I line strengths in the M92 and HD 140283 spectra may be consistent with an increased reddening. Regardless, the conclusion that either the  $[\text{Fe}/\text{H}]$  of M92 has been significantly overestimated from red giants or current reddening/photometry estimates are too small/red is not easily escaped. If the reddening/photometry were in error by this amount, turnoff color-based ages for M92 could be reduced by  $\sim 4$  Gyr. The adjustment to the M92 distance modulus required for a similarly reduced turnoff age that is luminosity-based can be accommodated by increases in extinction and alterations to the metal-poor field star distance scale recently inferred from *Hipparcos* Cepheid and subdwarf data.

Their M92 subgiants demonstrate  $[\text{Cr}/\text{Fe}]$ ,  $[\text{Ca}/\text{Fe}]$ , and  $[\text{Ti}/\text{Fe}]$  ratios that are unremarkable and essentially identical to the values for HD 140283.  $[\text{Ba}/\text{Fe}]$  is 0.45 dex larger for the M92 subgiants than for HD 140283. Surprisingly, they find  $[\text{Mg}/\text{Fe}]$  to be 0.55 dex lower in their M92 subgiants than in HD 140283, and  $[\text{Na}/\text{Fe}]$  to be 0.76 dex larger in their M92 subgiants than in HD 140283. These differences (and indeed nearly all their abundance ratios) seem immune to various data, analysis, and parameter errors. If real, this striking abundance pattern is suggestive of material in the M92 stars’ photospheres that has undergone  $\text{Ne} \rightarrow \text{Na}$  and  $\text{Mg} \rightarrow \text{Al}$  cycling like that inferred for red giants in M92 and other clusters. While this is generally believed to be an in situ process in cluster giants, the presence of abundant Li in the M92 stars suggests a polluting source acting either primordially or via accretion after cluster star formation.

It has been known for over a decade that Hyades F stars have severely depleted their Li abundances (the “Li gap”), in sharp contrast to the predictions of the standard stellar evolution theory. Deliyannis, Boesgaard, Stephens, King, and S. Vogt and M. Keane (Lick Observatory) reported the first results of a Li and Be survey aimed at identifying the physical mechanism that creates the Li gap. The survey included high-resolution ( $R = 48,000\text{--}120,000$ ) and high S/N observations in 24 stars of the Li I 6707.8 Å and/or the Be II 3131 Å doublets taken at the UH 2.2 m telescope, CFHT, and Keck I. The program stars with detections in both Li and Be define a clear trend that suggests (1) the surface Li and Be abundance depletions are correlated and (2) surface Li diminishes more rapidly than surface Be. The results suggest that correlated Li and Be depletion is a normal process that F stars undergo. The Li-Be trend argues strongly against the mass loss and diffusion mechanisms, and strongly supports slow mixing as the cause of the surface light-element deficiencies. Moreover, models with rotationally induced mixing are in better agreement with the data than models with wave-driven mixing.

The determination of the abundance of oxygen (O) is important in our understanding of mass-spectrum of previous generations of stars, the evolution of the Galaxy, stellar evolution, and the age-metallicity relation. Boesgaard, King, Deliyannis, and Vogt have measured O in 24 *unevolved* stars with Keck HIRES observations of the OH lines in the ultraviolet spectral region at a spectral resolution of  $\sim 45,000$ . The spectra have high S/N, typically 60–110, and high dispersion, 0.022 Å per pixel. Very special care was taken in determining the stellar parameters in a consistent way, and they have done this for two different, plausible temperature scales. The O abundance from OH has been computed by spectrum synthesis techniques for all 24 stars plus the Sun, for which we have a Keck spectrum of the daytime sky. Further, they determined O abundances from the O I triplet with our stellar parameters and the published equivalent widths of the three O I lines from six sources. The comparison of data analyzed with the same, consistently determined parameter sets shows generally excellent agreement in the O abundances; differences in the origin of the models (not the parameters) may result in abundance differences of 0.07–0.11 dex. The O abundances from OH and from O I are reliable and independent, and the two results were averaged to obtain the final adopted O. This averaging has the great benefit of neutralizing uncertainties in the parameters since OH and O I strengths depend on effective temperature and gravity in opposite directions. For these cool, unevolved stars, they find that O is enhanced relative to Fe with a completely linear relation between  $[\text{O}/\text{H}]$  and  $[\text{Fe}/\text{H}]$  over three orders of magnitude with very little scatter; taking the errors into account in determining the fits, they find  $[\text{O}/\text{H}] = +0.66 (\pm 0.02) [\text{Fe}/\text{H}] + 0.05 (\pm 0.04)$ . The O abundances from 76 disk stars of Edvardsson *et al.* have a measured slope of 0.66 (identical to our halo dwarf stars) and fit this relationship smoothly. The relation between  $[\text{O}/\text{Fe}]$  and  $[\text{Fe}/\text{H}]$  is robustly linear and shows no sign of a break at metallicities between  $-1.0$  and  $-2.0$ , as has been discussed by others. At low metallicities,  $[\text{Fe}/\text{H}] < -3.0$ ,  $[\text{O}/\text{Fe}]$  is  $> +1.0$ . The

fit to this relationship (taking the errors into account) is  $[\text{O}/\text{Fe}] = -0.35 (\pm 0.03) [\text{Fe}/\text{H}] + 0.03 (\pm 0.05)$ . The enrichment of O is probably from massive stars and Type II supernovae; however, the absence of a break in  $[\text{O}/\text{Fe}]$  vs.  $[\text{Fe}/\text{H}]$  runs counter to traditional Galactic evolution models, and the interplay of supernovae Type II’s and Type Ia’s in the production of O and Fe should be reexamined. It appears that either Fe or O can be used as a chronometer in studies of Galactic evolution.

C. Roddier and F. Roddier worked on new observations of T Tauri made with the Hokuapaa adaptive optics system. Comparison with previous observations showed evidence for fast-moving material with infall on the main star. The infrared companion was found to be definitely resolved with a diameter of 108 milliarcsec (15.2 AU at 140 pc). Its brightness peaked again in 1996, although the maximum was less pronounced than in 1990. Surprisingly, its orbital speed was found to exceed the escape velocity. This led to the conjecture that T Tauri is the result of a collision between a young star and a protostar, possibly explaining the peculiar molecular hydrogen emission found in this object. The protostar envelope would have been torn apart forming the Burnham nebula and leaving the protostar naked, i.e., visible in the infrared.

Heasley and K. Janes (Boston Univ.) have completed the photometric reductions for the metal-rich globular clusters NGC 6624 and NGC 6637. Both clusters are believed to be members of the “thick disk” located near the Galactic center. *HST* observations have been combined with ground-based data from the CFHT to yield color-magnitude diagrams that extend from the tip of the red giant branch to approximately 4 mag below the cluster turnoffs. Direct comparison of the color-magnitude diagrams indicates that the two clusters are identical in age within the uncertainties of the photometry.

Heasley and Space Grant student C. Law have reduced an extensive data set on the globular cluster M71. These observations complement the *HST* observations of NGC 6624 and NGC 6637 obtained with the *HST*, as M71 and 47 Tuc are the only thick disk globulars that can be readily observed with ground-based telescopes. The M71 observations include prime focus and HR Camera observations obtained with the CFHT, observations with the UH 2.2 m telescope, and wide-field observations from the Kitt Peak 0.9 m telescope. Only the latter set were obtained under photometric conditions. A preliminary comparison of the M71 color-magnitude diagram with those of NGC 6624 and 6637 suggests that M71 is younger than the other two clusters.

Heasley has begun a study on the calibration of the Population II main sequence using the *Hipparcos* database. The goal of this work is to define a sample of stars with both high-quality parallaxes from *Hipparcos* and self-consistent metallicity determinations. For the latter, stars have been selected from the studies of high proper motion stars by Carney, Laird, and Latham. Many of the low-metallicity stars in the latter sample appear to be subgiants and unsuitable for defining the metallicity dependence of the Population II main sequence.

## 9. SOLAR SYSTEM STUDIES

### 9.1 Planetary Atmospheres

F. Roddier and C. Roddier recorded images of Neptune with the Adaptive Optics system (Hokupaa) both in November 1997 and in July 1998. The images show high-altitude clouds above lower layers of haze.

Owen continued to participate in the analysis of the mass spectrometer data from the *Galileo* probe. Thanks to extensive laboratory studies by P. Mahaffy (Goddard Space Flight Center), it has been possible to determine the values of  $D/H = 2.6 \pm 0.7 \times 10^{-5}$  and  ${}^3\text{He}/{}^4\text{He} = 1.66 \pm 0.05 \times 10^{-4}$  in Jupiter's atmosphere. These results are consistent with a solar value of  ${}^3\text{He}/{}^4\text{He} = 4.4 \times 10^{-4}$  recently determined by the *Ulysses* spacecraft. Owen pointed out that the nearly identical enrichment of both carbon and sulfur in Jupiter's atmosphere requires the carrier of these elements to be icy planetesimals, as even the most primitive carbonaceous chondrites do not carry sufficient carbon.

### 9.2 Comets

Biver has been working on radio-wavelength observations of comets at large heliocentric distances. The long-term spectroscopic monitoring of comet C/1995 O1 (Hale-Bopp), now receding from the Sun for more than a year, is part of a worldwide collaboration that has been ongoing at the Swedish-ESO Submillimetre Telescope (SEST) in Chile since September 1997. The very last detections of the comet's CO(3-2) line were obtained with the JCMT in March and July 1998 to complement the data obtained at lower frequencies with SEST. In March–July 1998, CO and  $\text{CH}_3\text{OH}$  were detected at JCMT in the new comet C/1997 J2 (Meunier-Dupouy) when it was 3.2 AU from the Sun. These data provide complementary information about the behavior of comets at distances where water-ice sublimation may not dominate.

Biver is also working on the study of chemical composition of comets close to the Sun. The analysis of the data obtained in 1996 on comet Hyakutake from a collaboration between IfA, the Joint Astronomy Centre, and Paris Observatory has been completed and is to be published. An attempt (with Meier) to observe the new bright comet C/1998 J1 (*SOHO*) with JCMT was hampered by the lack of a good ephemeris on very short notice. A significant effort was made to make it close to a success, including imaging with the UH 2.2 m telescope (Hodapp) for astrometry and scheduling of a target of opportunity proposal for JCMT. OH was later detected in this comet (at Nancy), in a collaboration with J. Crovisier, D. Bockelée-Morvan, P. Colom, and E. Gérard (Paris Observatory).

Meech continued her long-term program of comet observations. The objectives of this study are (1) to search for physical differences in the behavior of the dynamically new comets (those which are entering the solar system from the Oort cloud for the first time) and the periodic comets, and (2) to interpret these differences, if any, in terms of their physical and chemical nature, and the evolutionary histories of the two groups of comets.

Observations of cometary comae at large heliocentric distances are now routine for the dynamically new comets, and this clearly indicates that there is a strong difference in the brightness curves of the Oort comets compared to the periodic comets. The dynamically new comets and the short-period comets are believed to have formed in different regions, with the short-period comets forming at lower temperatures, but the differences in activity levels seen between the comet classes are almost certainly due to evolutionary or aging effects. Observations using the Keck II telescope have found residual activity in one of the dynamically new comets, C/1987 H1 (Shoemaker), at a distance of 23 AU.

*HST* observations of 5 Oort comet nuclei by Meech and Hainaut (ESO) have yielded upper limits to the sizes of the nuclei. Imaging observations with the Keck II telescope have yielded size estimates for an additional 15 nuclei. The nuclei are quite small—comparable to the sizes of the known short-period nuclei. These data help confirm that the difference between the two groups of comets is caused by differences in intrinsic activity, not size. This result has important implications for the extreme activity levels in the Oort comets as well as for models of the outer solar system that suggest that the Oort comet size distribution should be primordial, but the short-period comets are probably collisional fragments from the Kuiper Belt. This work, in conjunction with the laboratory studies of low-temperature ice condensation that Owen and collaborators are working on, is building up a picture of the formation conditions in the early solar system.

Meech and graduate student J. Bauer have targeted for observation several selected comets that are candidates for future space missions. Several sets of observations have been conducted on 81P/Wild 2, the target of the NASA STAR-DUST mission, scheduled for launch in February 1999. The observations are being added to a 9 yr database. Models have been developed in collaboration with R. Newburn (Jet Propulsion Laboratory [JPL]) to assess the dust hazard for the spacecraft when it flies through the coma to collect dust samples.

Bauer and Meech have been observing selected bright comets using the UH 2.2 m telescope in conjunction with simultaneous X-ray observations obtained by collaborators C. Lisse *et al.* (Univ. of Maryland). The goal is to find a correlation between X-ray activity and outbursts in the dust production to discover the mechanism for the X-ray production.

Jewitt and H. Matthews (JAC) measured submillimeter continuum radiation from comet Hale-Bopp and used it to assess the total mass loss rate from this comet. They used the Submillimetre Common-User Bolometer Array (SCUBA) on the JCMT to map the comet. The submillimeter continuum provides a measure of the largest, most massive particles in the cometary dust size distribution. They found that Hale-Bopp released dust at  $2000 \text{ tonne s}^{-1}$  when at perihelion, and that at least 5 times more mass was lost as dust than in the form of sublimated ices. The low fractional ice content of the nucleus of Hale-Bopp is compatible with recent JCMT observations showing that dust/ice  $> 1$  is the norm in all the comets studied so far.

Jewitt, Matthews, Meier, and Owen measured the  ${}^{12}\text{C}/{}^{13}\text{C}$ ,

$^{14}\text{N}/^{15}\text{N}$ , and  $^{32}\text{S}/^{34}\text{S}$  isotope ratios in comet Hale-Bopp using the JCMT. These ratios were all consistent with standard solar system values, within the uncertainties, compatible with the formation of Hale-Bopp in the outer parts of the circumsolar accretion disk. The nitrogen and sulfur isotope determinations were the first obtained on any comet, demonstrating the power of submillimeter spectroscopy for this purpose.

The exceptionally bright comet Hale-Bopp provided a unique opportunity to study emission lines from minor species, including rare isotopes. Meier, Owen, Jewitt, and Biver, together with other collaborators, succeeded in measuring the D/H ratio in cometary water of Hale-Bopp with the JCMT. Within error bars, this ratio turned out to be identical to comets P/Halley and Hyakutake, i.e., about twice the SMOW value. In late April 1997 Meier *et al.* detected DCN with the same telescope. The detection of DCN is the first ever detection of a deuterium-bearing species in a comet other than water. With a  $\text{D}/\text{H} = (2.3 \pm 0.4) \times 10^{-3}$  in HCN, the ratio is different from the D/H ratio in water and roughly 2 orders of magnitude above the protosolar value. Meier *et al.* concluded that ion-molecule reactions or dust-surface reactions at low temperatures—an environment typically found in the interstellar medium—must be responsible for these deuterium fractionations.

Meier completed a detailed study of the NH and CH bands of comet Hyakutake in collaboration with Wellnitz, A'Hearn (Univ. of Maryland) and Kim (Kyunghee Univ., Korea). They investigated echelle spectra taken in the near-UV/visible at  $R \sim 18,000$  and with a superb signal-to-noise ratio. They showed that the CH  $A - X$  and  $B - X$  band systems can best be modeled with a single-cycle fluorescence model using different spin temperatures for the two different spin states. The different spin temperatures are explained by dissociative excitation and may help identify the parent species of CH. Three sigma upper limits for the D/H ratio in NH (0.006) and CH (0.03) were also derived from the same data set.

Owen participated in two consortia set up to search for D/H in comets Hale-Bopp and Hyakutake. One was headed by Bockl  e-Morvan, the other by Meier. Both groups were successful, and results were published in *Icarus* and *Science*. The outcome is that D/H in  $\text{H}_2\text{O}$  from both comets is about twice the value found in seawater, thereby establishing that Earth's oceans are not simply the result of melted comets. In addition, the D/H in HCN in Hale-Bopp is  $\sim 7$  times the value in  $\text{H}_2\text{O}$ . This result can be understood if both values were set by ion-molecule reactions in the interstellar medium, before the comet was formed. Owen suggested that cometary water might be found on Mars, where, unlike on Earth, there is little communication between the surface and interior.

### 9.3 Outer Solar System Objects

Using the facilities on Mauna Kea and at the Cerro Tololo Inter-American Observatory, Meech obtained several data sets to look for low levels of activity in distant solar system objects, including Centaurs, trans-Neptunian objects, and those objects believed to be asteroid-comet transition ob-

jects. Meech and her collaborators will compare the surface brightness profiles of field stars to the comets to place very sensitive upper limits on the amount of possible outgassing and dust loss. This technique will also provide data for analysis of the rotational light curve.

Tholen collaborated with A. Barucci (Paris-Meudon) to obtain *UBVRI* photometry of trans-Neptunian objects with the NTT at ESO. The data for a half-dozen objects have been reduced and a manuscript is nearing completion. A range of colors, from those similar to D-type asteroids to much redder ones, was found.

Jewitt continued a long-term investigation into the properties of the Kuiper Belt. With graduate student C. Trujillo and J. Luu (Harvard) he obtained new survey measurements at the UH 2.2 m telescope and at CFHT. These measurements will ultimately yield the size distribution, radial distribution, and inclination distribution of the Kuiper Belt objects. These three properties set fundamental constraints on the origin and dynamical evolution of the Kuiper Belt.

Jewitt and Luu obtained visible and near-infrared photometric observations of Kuiper Belt objects with the Keck telescope. These measurements show that a wide range of surface colors exist, with  $V - J$  providing the most powerful discriminant of the different types. The color dispersion appears unrelated to the distance, dynamical subtype, or diameter of the object. Its origin is unknown.

### 9.4 Rings and Satellites

Data taken by C. Roddier and F. Roddier in August 1995, when Earth was crossing Saturn's ring plane, provide evidence of an arc of particles near Enceladus' orbit. Data analysis showed it was a short-lifetime event possibly caused by the collision of a large ice block, recently ejected by Enceladus, with ice fragments trapped near the Enceladus L4 Lagrange point. This result will be published in *Icarus* and was also presented at the Nantes Symposium on the Jovian System after Galileo and Saturnian System before Cassini-Huygens (11–15 May 1998).

Deep images of Neptune taken in July with the Adaptive Optics system revealed four of the dark satellites discovered by Voyager II (Proteus, Larissa, Despina, and Galatea) as well as part of the Adams ring. The data will help improve their orbit determinations.

With C. Griffith (Northern Arizona State Univ.) and T. Geballe (JAC), Owen found a new window into Titan's atmosphere at  $2.7 \mu\text{m}$  that extends to  $2.9 \mu\text{m}$  and thus can be used from Mauna Kea. Observations of Titan at this and shorter wavelength windows revealed the presence of a bright cloud system in Titan's lower atmosphere. The frequency and duration of such clouds remains to be determined. By including observations at  $5 \mu\text{m}$  and using models developed by T. Roush (NASA Ames), Owen found a clear indication of the presence of water ice on Titan's surface. This is surprising in view of the continuous precipitation of organics—both aerosols and condensed hydrocarbons—taking place on Titan.

With Meier and Geballe, and D. Cruikshank, Roush, and C. Delle Ore (NASA Ames), Owen investigated the spectrum of the dark side of Iapetus in the *L* window with the

CGS4 spectrometer on UKIRT. There is very strong absorption that appears to be caused by a nitrogen-rich organic compound. It is now possible to look for this signature on other dark objects in the outer solar system to see if the same compound is present.

With Cruikshank, Roush, Geballe, Delle Ore, and C. de Bergh (Paris Observatory), Owen identified absorption by water ice in the spectrum of Phoebe in the *K* window. This is a clear demonstration that this captured satellite is not a vagabond C asteroid scattered from the main belt. This discovery invites similar studies of irregular satellites in the Jupiter system, as well as of the Trojan asteroids.

Tholen concluded observations of the Galilean satellite mutual events, where emphasis was on those events involving Io. The goal of the observations is to improve orbital theories for the satellite to the point where a more precise determination of the secular acceleration can be made and to compare that value to the one expected from heat flow measurements. Reduction and analysis of the observed events is continuing.

Smith and Meier continued their work as part of the NICMOS Guaranteed Time Observer program on the *HST*. Because NICMOS is running out of cryogen, the data-collecting phase will soon be terminated. So far, data from approximately 10 different proposals related to solar system objects have successfully been recorded. Highlights so far are high-quality surface maps of Titan in the near-infrared at several wavelengths; broadband photometry of the Jovian ring and its minor satellite Adrastea at 1.1, 1.6, and 2.05  $\mu\text{m}$ ; and four-color spectrophotometry of Neptune's cloud, which helps constrain the chemical composition of the bright clouds on Neptune.

### 9.5 Asteroids

Tholen and graduate student R. Whiteley continued a program to search for near-Earth asteroids with aphelion distances  $\leq 1$  AU. This effort requires observations at solar elongations of  $< 90^\circ$ . The second discovery to result from this work was that of 1998 DV9, which is an Apollo-type object with an estimated diameter of 900 m. A smaller and fainter object, 1998 DK36, was found on the same night and recovered on the following night but subsequently lost due to camera failure. However, the best-fitting orbit based on the four observations from those two nights yields an aphelion distance of 0.980 AU. Additional orbit fits to the observations with noise added suggests a high probability that the aphelion distance is less than 0.989 AU, which is Earth's heliocentric distance at that longitude, so it appears that 1998 DK36 is the first known example of an asteroid with an orbit that lies completely interior to the Earth's orbit. With a low inclination and a nearly tangential orbit, it is the kind of object that represents a relatively greater impact hazard, but would not be detected by opposition search efforts.

Tholen's program of asteroid physical observations emphasized planet-crossing asteroids, including primarily near-Earth objects and Kuiper Belt objects. The observations of the former group are being handled primarily by Whiteley as part of his thesis. In connection with this effort, Tholen as-

sisted with the initial recovery of the two new distant Uranian satellites discovered at Palomar by Gladman and Nicholson in late 1997.

Tholen continued to participate in the Small Bodies Node of the Planetary Data System. Together, Tholen and the Planetary Science Institute in Tucson represent the asteroid subnode, which collects and prepares asteroid data for archiving.

### 9.6 Spacecraft

Owen continues his participation in the *Galileo* Extended Mission, the *Cassini-Huygens* Missions, and the newly initiated *Comet Nucleus Tour (Contour)* Mission, which is under the direction of J. Veverka (Cornell).

Owen and Meier were selected as science team members for the *Deep Space 1 (DS1)* mission, the first of several missions within the New Millennium Program. The New Millennium Program is run by NASA/JPL to test new technologies and the rapid production of smaller and cheaper spacecraft. The primary goal of *DS1*, launched in late October 1998, is to test an ion propulsion system in space. The target asteroid is 1992 KD. Meier and Tholen have plans to support the *DS1* mission with ground-based observations from IRTF and the UH 2.2 m telescope.

## 10. SOLAR PHYSICS

The University of Hawaii at Manoa has been a world leader in solar physics for more than three decades. The Mees Solar Observatory (MSO) on Haleakala, Maui, is one of the handful of frontline ground-based solar observatories in the United States.

### 10.1 Estimation of Coronal Magnetic Field Structure

Graduate student L. Jiao successfully defended his Ph.D. thesis in May. The thesis, entitled "Reconstruction of the Three-Dimensional Solar Coronal Magnetic Field," compared *Yohkoh* Soft X-ray Telescope (SXT) images of coronal structure with computed models of the coronal magnetic field. He used the MSO Haleakala Stokes Polarimeter (HSP) vector magnetograms as a boundary condition to resolve the vector ambiguity and compute the vertical current density. He modeled the coronal fields with the evolutionary, nonlinear, nonconstant alpha force-free approximation. Jiao made nearly two dozen extrapolations for six active regions and activity complexes with a range of magnetic complexity and flare productivity. The excellent coverage of the MSO data made possible the selection of a variety of well-observed regions. Multiple observations within a day and over successive days gave confidence in the quality of the coronal field estimation. This work is the most comprehensive survey of coronal field estimates made with a single, uniform observational data set and state-of-the-art model. A sample of the initial results was published by Jiao, McClymont, and Z. Mikic (Science Applications International Corporation).

Jiao found that the computed magnetic free energy scales with the flare productivity of the region. Simple bipolar regions (AR 7216, 7330, 7335) with little flare activity had peak current densities of 10 to 20  $\text{mA m}^{-2}$  and free energies

in the range 2 to  $4 \times 10^{31}$  ergs. Complex, flaring regions (AR 6919, 7220, 7321) had 20 to 60 mA m<sup>-2</sup> and 1 to  $4 \times 10^{32}$  ergs.

There is substantial coronal magnetic structure that contributes to the emission structure seen by SXT, but that is at low altitude and has small spatial scale, and is therefore not resolved in the field extrapolations even in the simplest bipolar regions. An indicator of bright, short loops was the field strength at the footpoints. Those loops with both feet in regions with fields above 500 G generally were bright, relative to equal length loops with at least one footpoint in weaker fields. Separatrix locations determined from the field extrapolations show small, isolated features that sometimes match with the locations of flare kernels or unusually bright SXT loops. In complex regions, the twist of the field lines can be large, up to 180° along fields that are rooted in large opposite polarity sunspots.

## 10.2 Fluxtube Oscillations

Graduate student R. Kupke successfully defended her Ph.D. thesis in July. The thesis, entitled “An Observational Study of the Dynamic Behavior of Flux Tubes,” used the Mees CCD to record Stokes spectra of fluxtube oscillations. Kupke, working with Mickey, designed and constructed a polarimeter section in the coudé feed telescope at MSO. This permits the MCCD Imaging Spectrograph to function as a spectropolarimeter for high time cadence observations. Tests show the system to be quite clean in its polarimetric properties, with a calibration matrix that is highly diagonal dominant. Observations of fluxtube oscillations are the primary science goal for this instrument.

Kupke’s work was unique in several ways. First, she used a Fourier transform technique to measure the Doppler shifts of all four of the Stokes profiles. There are no previous observations of the shifts of the Q and U profiles, produced in transverse field regions. Second, she scanned the entirety of small spots to insure that all parts of the fluxtube were fully sampled. These characteristics permitted her to go beyond the recent work of Lites *et al.*

Kupke was able to measure velocity oscillations in all four Stokes components. At a single point, the velocities observed in I, Q, U, and V were highly correlated. Images of the velocity oscillation amplitude over the field of view showed that the amplitude was generally greatest where the Stokes component amplitude was greatest. That is, in areas of strong fields in the line of sight, motions were largely along the field, while in areas of strong fields transverse to the line of sight, motions were largely transverse to the field. This result implies both longitudinal and transverse waves present on field lines.

Kupke also detected an oscillation of the magnetic field strength, but only in a particular area at umbral-penumbral boundary. She could only see oscillation in the line of sight component of the field; the noise was too large to detect variation in the transverse component. She could not tell if the oscillation is a true strength variation or simply an inclination variation. The location of the oscillatory field suggests resonant oscillations in the region of steep field gradient at the umbral boundary. An analysis of the relative phase shifts

of the velocity and magnetic oscillations implies a power flow sufficient for coronal heating, of order  $10^7$  ergs cm<sup>-2</sup> s<sup>-1</sup>. The restricted area showing magnetic oscillations may explain why only some field lines are heated at a given time.

## 10.3 Polar Plumes

J.-P. Wülser (Lockheed) and Mickey completed the analysis of Imaging Vector Magnetograph (IVM) data taken in coordination with the March 1996 *SOHO* polar plumes campaign. The principal question was the determination of the orientation of the photospheric magnetic fields with respect to the overlying coronal structures. The vector magnetic field observations taken with the IVM provide the opportunity to follow the field orientations to the surface level.

Wülser and Mickey combined the data from an entire 30 magnetogram movie of the polar cap to increase the sensitivity to the field azimuths. They found no evidence in the photosphere for superradial orientation of the fields, as is seen in the corona. The purely radial orientation of the fields in the photosphere is not too surprising, given the ratio of gas and magnetic pressures. It does set a limit on the height below which field lines respond to the overlying coronal field structure.

## 10.4 Isolated Active Regions

LaBonte, H. Hudson (Space Physics Research Center), A. Sterling (Naval Research Laboratory), and T. Watanabe (NAOJ) have worked on the isolated active regions AR 7978/7981 from July and August 1996. This complex is very interesting because its appearance on an otherwise blank Sun makes it a “test particle” for understanding the nature of its activity and its effects on the global corona. Statistical study of the soft X-ray events is the primary focus of this study. The variance of the X-ray flux was detectable down to time-scales of 1 min, with no indication of a “smoothing” from the long formal cooling times of the coronal gas. The times of occurrence and magnitudes of the flares of this region show no indication of obeying a relaxation oscillator. During its second disk passage as AR7981, the decay of sunspots and magnetic complexity as observed with the IVM was accompanied by an increase in the flare rate and flare sizes. The effects of this region in energizing an entire hemisphere of the corona are dramatically seen in the SXT images for July 1996.

## 10.5 Acoustic Imaging

LaBonte collaborated with H.-K. Chang and D.-Y. Chou (Tsing Hua Univ.) and others in demonstrating a new method for observation of magnetic and other structures below the solar surface. In a process analogous to viewing of objects via ambient light, structures inside the Sun can be observed with ambient sound. Each spatial location on the solar surface responds to acoustic waves striking that location. By treating an array of locations as a phased array of hydrophones, they can shift the detected signals and sum to produce the signal from any point in the solar volume.

They generated a time series of acoustic phase shift images of AR 7981 over 1–3 August 1996. The images were

examined to measure the time delay between the appearance of emerging magnetic flux at the solar surface and in the acoustic images. They were not able to detect a time difference, with an upper limit of 8 hours. This implies that identifying the magnetic structure below the surface may be difficult in the presence of high contrast acoustic features at the surface. This is consistent with the findings of D. Braun and collaborators that the acoustic images are dominated by surface features.

### 10.6 Image Reconstruction for Stokes Polarimetry

The Imaging Vector Magnetograph (IVM) at Mees Solar Observatory is designed to measure the magnetic field vector over active region sized areas of the Sun. The first step in that process is the correction of the raw data for all known systematic effects introduced by the instrument and Earth's atmosphere. Mickey, LaBonte, and K. Leka (Colorado Research Associates) completed the first functional model of the atmosphere/instrument system and measured the corrections for the degradation introduced by each component of the model. The removal of parasitic light and scattered light make the largest improvements in the Stokes I parameter. Particularly important are the use of the second channel of images, taken in the unpolarized continuum, to measure and remove the effects of differential seeing and image motion. The corrections are applied to standard observations, and reductions of the spurious polarization induced by atmosphere and instrument by up to a factor of 10 are found. This analysis procedure is now in regular use for the reduction of all IVM data.

### 10.7 Polarimeter Intercalibration

Mickey, LaBonte, and Leka have made a quantitative comparison of the Stokes spectra taken with the IVM and the High Altitude Observatory's Advanced Stokes Polarimeter (ASP). These two instruments represent the state of the art in vector magnetography, but have radically different design. The comparison was conducted with normal daily magnetogram observations to assess the instrument performance under typical conditions. After correction for known instrumental properties, the data indicate a better match than any of the previous magnetograph intercalibrations. Polarization amplitudes scatter about the mean trend line to within the noise level, about 0.1% in Q, U, or V integrated over one side of the spectrum line. Some systematic deviations of the trend line from the ideal are seen at the 1% level in V and 0.02% level in Q and U. The ability to carry out spectropolarimetry with independent instruments at this precision and accuracy is reassuring for quantitative measurements of the vector magnetic field.

The interpretation of the Stokes spectra to derive magnetic field parameters differs for the normal magnetogram observations. Field orientation appears to be well measured in sunspots, with scatter in the azimuth angle of about 10° in general. However, there are some locations in the sunspot with unusual spectra that fall off the trend line and are being studied. Improved methods for deriving the field parameters from the Stokes spectra are being tested, to make the analysis

more model independent. The ongoing upgrade of the IVM to include a tunable prefilter will permit observation of both lines of the Fe I multiplet at 630 nm. They will be able to process the IVM data with the same analysis procedures as are applied to the ASP data, further bringing the instruments onto a common system of high measurement accuracy and precision.

### 10.8 IVM Data System Upgrade

The IVM at Mees was designed optically and mechanically to make continuous observations. In operation, the data rate was limited by the data system: the CCD camera controllers, control computer, mass storage devices, and analysis computers. The most serious problems were the age and slow speed of the embedded Sun-3 control computer, the slow speed of the 8 mm tape drive, and the limited memory and disk storage. With all these problems, the staff was unable to make full field-of-view, full-resolution magnetograms, and they had to make magnetogram movies at 8 min cadence, alternating a magnetogram observation and its storage to tape. Analysis of the IVM data was also a problem, with the full reduction, including the image reconstruction, taking several hours on the available workstations.

With present funding, the 7 yr old data system has been replaced with a more modern one. The embedded control computer was replaced with a general purpose workstation connected through a VME to Sbus convertor. This element of the upgrade had to be rushed into operation when the embedded processor actually failed. The control workstation has more than adequate performance to store the data as fast as it is read from the cameras. The staff is now regularly making magnetogram movies at 3 min cadence, beginning almost simultaneous with the launch of *TRACE*. The control workstation can itself do data reduction, and augmented with two dedicated analysis workstations, they now can complete the science-grade reduction of an entire day of observations in one day. Those reduced magnetograms are now being put into the online archive, which is summarized on the MSO Web site. The final element of the upgrade, the replacement of the CCD camera controllers, was scheduled for October 1998. At that time, they will be able to regularly observe with the native 0.6 pixels, rather than the current 1.2 (binned 2) format. The new controllers will also operate 50% faster. Including the ability to use the full well capacity of each pixel, the total improvement in S/N achieved per unit time is a factor of 8 over the preupgrade instrument. This is a substantial resource for the study of activity in the present sunspot cycle.

### 10.9 NASA Mission Support

In recent years the IfA Solar Group and MSO have directly supported about six preplanned special observing campaigns per year involving NASA spacecraft such as *Spartan*, *Yohkoh*, *SOHO*, *TRACE*, and sounding rockets such as SERTS and HRTS. Separate *Yohkoh* funding has supported continuous collaborative science and observations with that mission. In addition to preplanned campaigns, MSO regularly supports the daily plans of these missions. During the



report period, there was a program to crosstrain MSO technical support personnel so that they are now able to operate the critical instruments. This permits MSO to carry out observations when the regular observer is sick or on vacation. The *TRACE* continuous observing campaign in May 1998 was supported in this mode, greatly increasing vector magnetogram coverage of the target, AR8227.

MSO services about two dozen requests for science-grade data from professional solar physicists per year. Most requests are from scientists in the United States and Japan, but they include requests from scientists in about a dozen nations in Europe and Asia. Mees data has had a significant impact on the solar physics community. Its data has been used in an average of almost one published paper or meeting presentation per month during 1997–98, in addition to the results published or presented by the IfA Solar Group.

Public outreach is a significant component in the success of the NASA space science mission. IfA Solar Group/MSO responds to several dozen individual requests per year from the general public for information on solar physics. The Hawaii Solar Astronomy Web site (<http://www.solar.ifa.hawaii.edu>) receives about 10 million visits per year, about half to its solar data and half to its weather data. Originally begun as an aid to operations planning, the tropical storm pages are widely known from their citations on the Federal Emergency Management Agency and Cable News Network Web sites.

## 11. THEORETICAL STUDIES

Barnes is writing new software for running and reducing N-body and SPH simulations. Compared to existing systems such as NEMO and TIPSy, the new system imposes fewer restrictions on the kind of data associated with each particle and avoids allocating unneeded space for particle data. While this software is targeted for the SGI O2 system Barnes recently acquired, much of it has also been tested on Sun and IBM machines. The software includes a tree code based on an improved force calculation algorithm that is faster and more accurate than earlier implementations. This algorithm is extensively documented at <http://www.ifa.hawaii.edu/~barnes/software.html>, which also has links allowing the reader to view and download the code. A preliminary version of an SPH code has also been developed; eventually this code will be made available via the Web.

Barnes developed an “identikit” system to efficiently match simulations to observations of interacting galaxies. A tree code is used to follow the self-consistent interaction of two dark halos, each containing a number of test-particle disks. Once the simulation has been run, an interactive viewing program is used to select the viewing angle and choice of disks that best reproduce the observations; colors are used to indicate line-of-sight velocities. This software has been used to produce models matching 21cm observations NGC 4038/9 by J. Hibbard (NRAO), T. van der Hulst (Kapteyn), and Barnes.

Kofman, graduate student P. Greene, and A. Starobinsky (Landau Institute, Moscow) have considered the instability of fluctuations in an oscillating scalar field that obeys the Sine-Gordon equation. They have presented simple closed-

form analytic solutions describing the parametric resonance in the Sine-Gordon model. The structure of the resonance differs from that obtained with the Mathieu equation, which is usually derived with the small angle approximation to the equation for fluctuations. The results are applied to axion cosmology, where the oscillations of the classical axion field, with a Sine-Gordon self-interaction potential, constitute the cold dark matter of the universe.

Kofman and Greene have explored reheating of fermions in inflationary cosmology. They find fermion preheating differs significantly from the perturbative expectation. It turns out that the number density of fermions varies periodically with time. The total number of fermions quickly saturates to an average value within a broad range of momenta  $\propto q^{1/4}$ , where  $q$  is the usual resonance parameter. The resonant excitation of fermions may affect the transfer inflaton energy, estimations of the reheating temperature, and the abundance of superheavy fermions and gravitinos. Back in the bosonic sector, outside of the parametric resonance bands, there is an additional effect of parametric excitation of bosons with bounded occupation number in the momentum range  $\propto q^{1/4}$ .

Kofman and collaborators have studied the production of cosmic strings from preheating in nonthermal phase transitions that may occur after postinflationary preheating. They use three-dimensional lattice simulations to investigate the full nonlinear dynamics of the model. They find that fluctuations of the fields generated during and after preheating temporarily make the effective potential convex in the  $\phi_1$  direction. The subsequent nonthermal phase transition with symmetry breaking leads to formation of cosmic strings even for  $v \gg 10^{16}$  GeV. This mechanism of string formation, in a modulated (by the oscillating field  $\phi_1$ ) phase transition, is different from the usual Kibble mechanism.

Kofman and collaborators have explored first-order non-thermal phase transitions after preheating. During preheating after inflation, parametric resonance rapidly generates very large fluctuations of scalar fields. In models where the inflaton field  $\phi$  oscillates in a double-well potential and interacts with another scalar field  $X$ , fluctuations of  $X$  can keep the  $\phi$  to  $-\phi$  symmetry temporarily restored. If the coupling of  $\phi$  to  $X$  is much stronger than the inflaton self-coupling, the subsequent symmetry breaking is a first-order phase transition. They have demonstrated the existence of this nonthermal phase transition with lattice simulations of the full nonlinear dynamics of the interacting fields, which show the nucleation of an expanding bubble.

Kaiser has developed a new way to measure the shear field for weak gravitational lensing. The new approach improves on previous methods in a number of respects; the effect of finite instrumental resolution is properly accounted for, as are a number of subtle biases that have hitherto been ignored. His analysis reveals an important distinction between the cases of seeing limited by ground-based turbulence and seeing limited by space-based diffraction. It is shown that the commonly used approximations for dealing with finite resolution and instrumental image anisotropy are not valid in the latter case, and alternative methods are presented that can cope with both space- and ground-based observations in a unified manner.

## 12. COMPUTER DIVISION

Some of the Sun 4 servers and workstations were upgraded to UltraSPARC servers and workstations. In 1999, the rest of the Sun 4 servers will be upgraded. Plans are underway to rewire the IfA building in Manoa to support Fast Ethernet.

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